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Beauty and Charm physics at CDF, first results and perspectives.

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1 Introduction

Among CDF physics opportunities, heavy flavour physics is one of the most prominent and promising for the Tevatron run2. Still in the run1 CDF demonstrated that high precision CP violation measurement in the beauty sector as well as B mixing are feasible at hadronic collider, we think here especially to the first measure of $sin2\beta$ with $B^0 \rightarrow J/PsiK_s^0$ decays and that of Δm_{Bd} (see [1]). Tevatron accelerator and CDF detector upgrades are extensively discussed in other papers to which we refer to (see [2]). Here we just recall the new features relevant to heavy flavour physics:

- New muon detector coverage up to $|\eta| < 1.5$ and lower p_T threshold for single and dimuon triggers.
- New Time of Flight detector (TOF) placed at $R = 1.4m$, made of 216 scintillator bars. The TOF resolution is 100 ps allowing a K/π separation at 2 σ for $p_T(K) < 1.6GeV$ (see [3]). With this upgrade the effective dilution ϵD^2 of flavour tagging algorithms will reach 11.3 % (5.7 % in run1).
- Completely new Silicon Vertex detector SVXII of 5 double layers, other 2 external silicon layer ISL and additional silicon layer L00 at 1.5 cm from the beam pipe; will enhance vertex resolution and acceptance.
- Trigger system based on L1 fast tracking XFT in the drift chamber and L2 secondary vertex selection through impact parameter measurement based on silicon hits (SVT) gives online rejection of prompt background and direct access to hadronic HF decays (details in [4]).

Recent CDF results based on both the lepton and SVT hadronic trigger samples are presented in the following, together with highlights of heavy flavour physics prospects and plans for run2a.

2 Leptonic sample

The first CDF high statistic b-physics sample is the one collected with the muon trigger. In particular since the beginning of the run a large number of $J/\Psi \rightarrow \mu\mu$ have been reconstructed thus allowing a detailed study of the

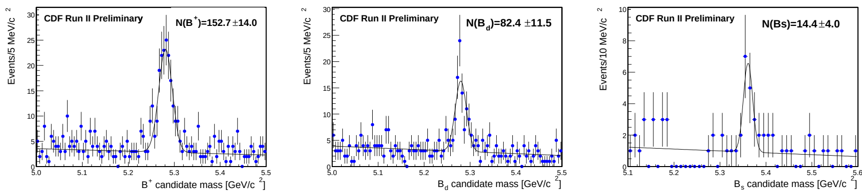

Fig. 1. $B^+ \to J/\Psi K^+$ (left), $B^0 \to J/\Psi K^{*0}$ (center) $B_s \to J/\Psi \Phi$ (right) invariant mass distributions, the unbinned likelihood fits are superimposed.

tracking system performances as well as the detector full simulation tuning. By comparing the reconstructed J/Ψ mass to the nominal PDG value a detailed correction for the energy loss by the tracks in the detector material has been implemented in the simulation eliminating the $P_T(M_{J/\Psi})$ momentum scale dependence. The material added in the simulation was found compatible with the detector material distribution obtained from conversion electron study on data. Tiny magnetic field correction factor has been also applied. This momentum scale tuning based on J/Ψ has been confirmed on other reconstructed $\mu\mu$ resonances like $Y(1s)$, $Y(2s)$, $Y(3s)$ which showed invariant masses values compatible with PDG values. Relying on this result we measured on the leptonic trigger sample the masses and lifetimes of B mesons on both exclusive and inclusive final states involving J/Ψ, using the data collected in the dimuon trigger till July 2002 corresponding to 18.4 pb^{-1} of integrated luminosity. Masses of B_u B_d and B_s mesons were measured respectively on the exclusive modes $B^+ \to J/\Psi K^+$, $B^0 \to J/\Psi K^{*0}$ and $B_s \to J/\Psi \Phi$ with $\Phi \to KK$. In these channels we collected $N_{B^+} = 152.7 \pm 14.0$, $N_{B^0} = 82.4 \pm 11.5$ and $N_{B_s} = 14.4 \pm 4.0$, the corresponding invariant mass peaks are shown in figure 1. The fit results for the masses are:

$$
\begin{aligned}
M_{B^+} &= 5280.6 \pm 1.7(stat) \pm 1.1(syst) MeV/c^2 \\
M_{B^0} &= 5279.8 \pm 1.9(stat) \pm 1.4(syst) MeV/c^2 \\
M_{B_s} &= 5360.3 \pm 3.8(stat) + 2.1/-2.9(syst) MeV/c^2
\end{aligned} \tag{1}
$$

The precision of B mesons masses is statistically dominated for the time being, they are still in very good agreement with the world averages. M_{B_s} is already the world second best single measurement. To have an independent cross check of the reconstruction and fitting algorithms the higher statistic and topologically similar channel $\Psi' \to J/\Psi \pi\pi$ was used as monitor. The measured Ψ' mass in that channel is $M_{\Psi'} = 3686.43 \pm 0.54(stat) MeV/c^2$ (PDG value: $M_{\Psi'} = 3685.96 \pm 0.09 MeV/c^2$).

Vertexing resolution performances are also well under control as well as silicon detector alignment, allowing us to measure inclusive b hadron lifetime. This has been done using the same full dimuon trigger sample containing $\sim 28000 J/\Psi$ produced either directly at primary vertex of $p\bar{p}$ interaction

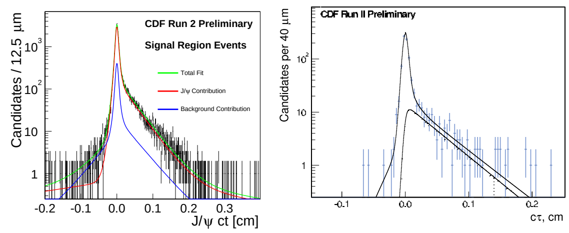

Fig. 2. Left: Inclusive b proper time fit results projected onto the data in the J/Ψ signal region. Right: the exclusive B proper time distribution in $B^{\pm} \rightarrow J/\Psi K^{\pm}$ candidates passing selection cuts, the result of the M.L. fit is overlaid.

("prompt" J/Ψ component) or through $b \rightarrow c\bar{c} + X$ ("lifetime" component). The $c\tau(J/\Psi)$ distribution is plotted in figure 2 (left). The $c\tau$ has been corrected with Montecarlo to account for the partially reconstructed decay. J/Ψ from primary vertex has been used to study the resolution function. The obtained b hadron inclusive lifetime:

$$c\tau_{inc} = 458 \pm 10(stat) \pm 11(syst)\mu m \tag{2}$$

is the result of an unbinned likelyhood fit containing the shapes of the "prompt" and "lifetime" components as well as that of the background taken from J/Ψ side-band convoluted with resolution function. The good control of silicon detector alignments and of vertexing resolution show up in a small systematic error. In all the analysis presented by the CDF collaboration so far neither the innermost silicon layer (L00) nor the z information of the silicon hits are used. Significant improvements are expected in vertexing and momentum resolution once this informations will be available.

The lifetime of B_u meson has been measured in the exclusive channel $B^{\pm} \rightarrow J/\Psi K^{\pm}$ relying on the ~ 150 events contained in the same dimuon trigger sample. The $c\tau(B^+)$ distribution is plotted in figure 2 (right) and it is modeled by an exponential long life component convoluted with a gaussian resolution function, the result is:

$$\begin{aligned} c\tau(B^+) &= 446 \pm 43(stat) \pm 13(syst)\mu m \\ \tau(B^+) &= 1.49 \pm 0.14(stat) \pm 0.04(syst)ps \end{aligned} \tag{3}$$

in good agreement with PDG value although statistically dominated so far.

3 Hadronic sample

We present here some preliminary results from the SVT hadronic trigger sample in which up to now CDF collected an effective integrated Luminosity of around 10 pb^{-1}. As highlighted in the introduction SVT has been designed to select long lived $b\bar{b}$ and $c\bar{c}$ events among the huge prompt QCD

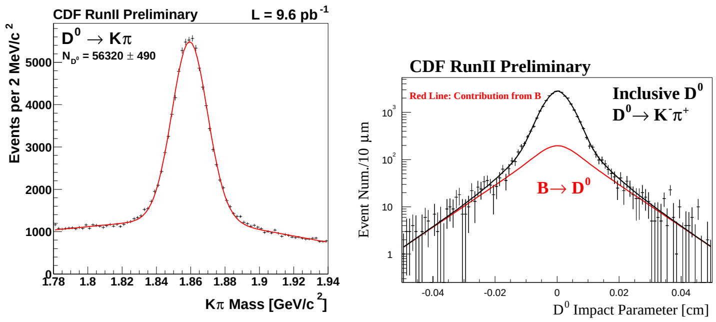

Fig. 3. Left: $D^0 \to K\pi$ candidates in the SVT trigger sample. Right: D^0 mesons impact parameter distribution, the contribution of D^0's from B decays in the tails (in red) is superimposed to the total (in black).

background, relying on significant impact parameter request on tracks. It is the first time that heavy flavour events are collected in a collider experiment without explicitly requiring a lepton, thus giving access to a great variety of fully hadronic decays of b and c hadrons. A very large sample of D mesons has been collected in this trigger, which is a clear sign of a relevant charm production cross section in $p\bar{p}$ interaction at $\sqrt{s} = 1.96$ TeV. In particular we reconstructed around 56000 D^0 meson decaying to $K\pi$ as can be seen in figure 3 (left). The D^0 meson sample allowed a detailed understanding and optimization of the hadronic trigger and its simulation as well as for the detector resolution, playing on this items a major role equivalent to that of J/Ψ's in the typical lepton triggers. The relative composition of SVT trigger sample in terms of b and c quarks has been studied exploiting the high vertex resolution in hadronic decays reconstruction by tracing back the D meson direction and measuring its impact parameter with respect to primary vertex. D mesons produced at PV are expected to have a null impact parameter (IP) within the resolution while D mesons from $B \to D + X$ will show up in the impact parameter distribution as a long life component, see figure 3 (right). Depending on the IP resolution parametrization modeled both with $K_s \to \pi\pi$ IP distribution in the hypothesis that K_s are mostly prompts or with a simple gaussian model, we obtained for the component ratio $R_{bc} = b\bar{b}/c\bar{c}$ in the SVT trigger, respectively $R_{bc} = 16.4 \pm 0.7\%$ and $R_{bc} = 23.1 \pm 0.6\%$. The first method is an underestimation of R_{bc} since it neglects secondary K_s while the second could overestimate R_{bc} fraction disregarding non gaussian tails in IP detector resolution.

Significant number of Cabibbo suppressed decays of D^0 meson has been observed in the modes $D^0 \to \pi\pi$ and in KK, the invariant mass distributions are shown in figure 4. Since this $\pi\pi$ and KK decays of D^0 are collected with exactly the same two track trigger it is possible to measure their widths relative to that of the $K\pi$ mode. The results based on 9.6 pb^{-1} of run2 SVT

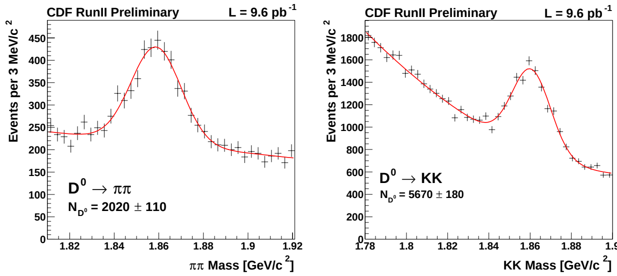

Fig. 4. $D^0 \to \pi\pi$ (left) and $D^0 \to KK$ (right) candidates invariant masses.

data are [5]:

$$\Gamma(KK)/\Gamma(K\pi) = 11.17 \pm 0.48(stat) \pm 0.98(syst)\ \% \tag{4}$$
$$\Gamma(\pi\pi)/\Gamma(K\pi) = 3.37 \pm 0.20(stat) \pm 0.16(syst)\ \%$$

Even at this early run2 stage this results are at the same level of precision of the world best single measurements done by CLEO2 [6]. Most of systematic cancel in the ratio while higher order relative acceptance correction are done through simulation and treated as systematic contribution. In particular in the KK channel the more relevant contribution to systematic error comes from background models. Other sources are the momentum spectra at production given as inputs to the trigger simulation and the detector and trigger simulation itself.

Using the same trigger systematic cancellation in similar or identical final states, the mass difference between D_s and D^+ mesons has been measured by reconstructing in the same SVT sample $D_s, D^+ \to \Phi\pi, \Phi \to KK$. The two peaks are shown in figure 5. The enhancement of D^+ decay to this suppressed mode is an artifact of trigger bias which prefers long lifetime decays ($c\tau(D^+) \simeq 2c\tau(D_s)$). The preliminary result is already competitive:

$$\Delta m(D_s - D^+) = 99.28 \pm 0.43(stat) \pm 0.27(syst) MeV/c^2 \tag{5}$$

In the same hadronic sample from the early Luminosity collected by CDF in the SVT trigger, the first B mesons decaying to fully hadronic final states has been observed. Particularly relevant are the $B^\pm \to D^0\pi, D^0 \to K\pi$ shown in figure 6 (left) and $B_{d,s} \to hh$ where hh stands for 2 hadrons; in figure 6 (right) the 2 π mass hypothesis is adopted, the peak is the super-position of $B_d \to \pi\pi, K\pi$ and $B_s \to KK, K\pi$. Respectively 56 ± 12 and 33 ± 9 signal events are observed in those modes.

4 Beauty and Charm perspectives

Among the large number of analyses in the B sector which are in the reach of CDF with the 2 fb^{-1} of run2a, the measurement of $B_s \div \bar{B}_s$ oscillation

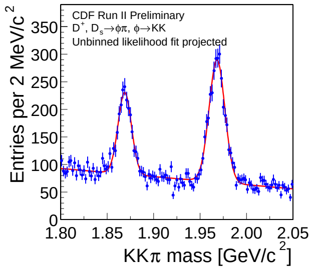

Fig. 5. $\Phi\pi$ with $\Phi \to KK$ mass distribution, there are ~ 1400 D^+ and ~ 2400 D_s candidates in this mode in 11.6 pb^{-1} of integrated luminosity by SVT.

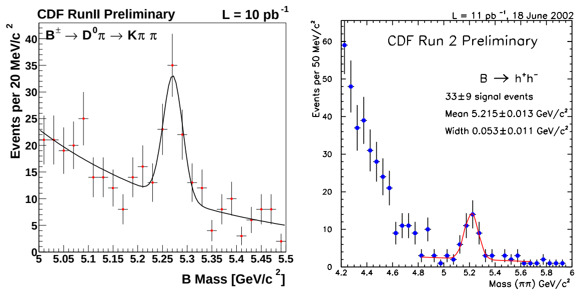

Fig. 6. $B^{\pm} \to D^0\pi$ with $D^0 \to K\pi$ candidates (left), $B \to 2$ hadrons with $\pi\pi$ mass hypothesis (right); reconstructed in the hadronic trigger SVT.

frequency Δm_s is one of the most relevant. The most recent limits from LEP searches constrain $\Delta m_s > 14.4 ps^{-1}$ at 95% CL; on the other hand CKM triangle global fit limits Δm_s to an upper bound of $24.6 ps^{-1}$ with 95% CL. In 2 fb^{-1} CDF expects to collect about 75K B_s decays to $D_s\pi, D_s\pi\pi\pi$ with $D_s \to \Phi\pi, K^*K, K_sK$ in the hadronic trigger. Considering a decay time resolution of 60 fs (45 fs with L00), an effective dilution for flavour tagging $\epsilon D^2 = 11.3\%$ and a S/B ratio between 0.5 and 2, CDF will have a 5σ sensitivity for a $\Delta m_s < 45 ps^{-1}$ thus largely exceeding the Standard Model expectations. Actually the CKM global fit range will be in principle covered with order 10 % of the total prospected integrated luminosity. A crucial point will be the flavour tagging algorithms among which the opposite side and same side (B_s hadronization) Kaon tagging both based on K identification with TOF, will play a major role. In order to measure ϵD^2 with required accuracy, a new trigger path has been implemented. It's a lepton (e, μ) plus displaced track trigger (SVT impact parameter request). This sample is enriched in semileptonic B and D decays in the same low p_T range of B_s decays; it will also be the starting point toward promising CKM elements V_{cb} and V_{ub} measurements through inclusive and exclusive semileptonic B decays. Another promising topic for CDF will be the study of CP asymmetries in the $B \to hh$

decays to two charged particles like $B_d \rightarrow K\pi, \pi\pi$ and $B_s \rightarrow K\pi, KK$ exploiting the SVT trigger capabilities. The unique feature at Tevatron is the contemporary presence of both B_d and B_s mesons thus opening the possibility to extract $sin\gamma$ from those A_{CP} as suggested in [7]. This measurement will rely on the particle identification performance based on dE/dx from the drift chamber ($\sim 1.3\,\sigma$ separation power for $p_T > 2$ GeV) for the π and K in the final states. Mixing measurement will separate B_d from B_s components. Particle identification with dE/dx will be controlled on the kinematically similar sample of D^0 with high statistics. B physics plans on all other topics are discussed in detail in [8].

In the Charm sector, CDF is already a high statistics experiment, as highlighted previously in this article. The charm production cross section will be measured for the first time at $p\bar{p}$ collider using SVT sample, giving a considerable input to QCD theoretical calculations. Given the recent optimization in SVT efficiency we can at present foresee to collect $\sim 750000 D^0 \rightarrow K\pi$ and $\sim 250000 D^* \rightarrow D^0\pi$ per 100 pb^{-1} of integrated luminosity. This opens the way to the measures of $D^0 \div \bar{D}^0$ mixing parameter y via lifetime differences (between D^0 CP eigenstates and CP mixed states) and to direct CP asymmetries in D decays (using the strong interaction D^* tag), with a precision competitive with present and near future experiments. A program of searches for rare and forbidden charm decays is also going on. CDF results on charm physics together with its impact on the knowledge of CP violation, will bring in the next years important informations in this field before the charm factory CLEO-C [9]. The present CDF detector performances are compatible with expectations and already very close to final ones. First competitive measurements in the HF sector presented here, demonstrate the very good understanding of detector and systematic control. The new hadronic SVT trigger is already selecting large samples of HF, and will be the key point for beauty and charm physics reach.

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